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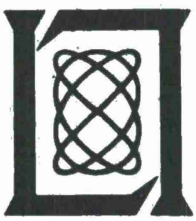
Quarterly Technical Summary

General Research

15 November 1968

Prepared under Electronic Systems Division Contract AF 19(628)-5167 by

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Lexington, Massachusetts



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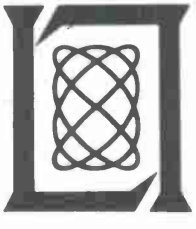

INTRODUCTION

This Quarterly Technical Summary covers the period from 1 August through 31 October 1968. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 August through 31 October 1968 for the General Research Program of Division 2. Separate progress reports on the Re-entry Systems Program, Graphics, STO-ARPA, ABMDA, and KMR describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, 26, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1968

PUBLISHED REPORTS

Journal Article*

JA No.			
3190	Surface Potential of a Free Electron Metal in the RPA	R. W. Davies	Surface Sci. 11, 419 (1968)

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
3211	Methods for Improving the Signal-to-Noise Ratio of Photon and Electron Beam Accessed Magnetic-Film Memory Systems	D. O. Smith	Accepted by IEEE Trans. Magnetics
3283	Feasibility of Lorentz Readout of a High-Density Fast Magnetic Memory	M. S. Cohen	Accepted by IEEE Trans. Magnetics

Meeting Speeches†

MS No.			
2303B, C	Photon and Electron Beam Accessed Memory Systems	D. O. Smith	Seminar, Ford Scientific Laboratory, Dearborn, Michigan, 3 October 1968; Seminar, M. I. T., 24 October 1968
2348	The Strain Sensitivity of the Wall Coercive Force in Magnetic Films	T. S. Crowther	Magnetism and Magnetic Materials Conference, New York, 18 – 21 November 1968
2395	A Subnanosecond ECL Circuit Produced with the Aid of Computer Graphics	D. J. Eckl K. H. Konkle W. R. Sutherland S. Idzik‡ R. Luce‡	IEEE Electron Device Meeting, Washington, D. C., 23 – 25 October 1968

* Reprints available.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

‡ Author not at Lincoln Laboratory.

DIGITAL COMPUTERS
GROUP 23

I. CIRCUIT AND NEW MACHINE DEVELOPMENT

A. Semiconductor Processing

Two chains of SMX12 ECL gates were fabricated by wire bonding to enable propagation delay measurements to be made. Measurements show the delay to be about 0.7 nsec per stage.

The mask drawing program is being used to make masks for similar monolithic chains — one with a 10-mw gate, the other with a 5-mw gate. Each chain will have one input gate which drives one output stage directly, and a second output stage through four intervening gate stages. Thus the time difference between the two outputs will represent the delay through four gate stages. Each gate chain will have, in addition to the seven gate stages, a reference bias generator. Measurement results will determine which configuration will be used in the microprocessor. This monolithic chip will contain a number of evaluation and test devices in addition to the two gate chains. There will be 10 test transistors and 12 test resistors to be used for device parameter measurements and circuit breadboarding. In addition, test devices will be provided to enable measurements of sheet resistance for base, emitter, and collector diffusions as well as via resistance and metal line resistance.

The mask program was used to design a thermal measurement chip consisting of 160 point heat sources of 500 ohms each. Five-thousand-ohm temperature sensing resistors are also placed at various points on the chip.

B. Chip Interconnection

The feasibility of interconnecting integrated circuit chips by depositing and photoetching layers of chemically deposited metals is being investigated. This is an extension of work done previously in which discrete electronic components, embedded in plastic, were successfully interconnected by means of chemically deposited connections and wiring.

The investigation will include tests of various metals chemically deposited onto aluminum, construction of alignment apparatus to accurately position and bond individual chips to a metal substrate, plastic encapsulation procedures and, as mentioned, deposition and photoetching of metallic layers including multiple layers if the initial work is successful.

C. Testing Terminal

The TX-2 testing terminal (TIC) is to be augmented with a small dedicated machine. The new terminal, called T^3, will connect to the TX-2 via a relatively low bandwidth link; the TX-2 will be used primarily for bulk storage of test results. T^3 will have a disk memory of sufficient size and speed to allow for large test programs and data files.

We feel that it is necessary that design engineers and technicians do their own applications programming and interfacing of test equipment. Therefore, we plan to implement a single-language operating system for the small machine which is easy for nonprogrammers to use. The language will be interpreted on T^3 in order to provide superior debugging aids and protection.

Later, a compiler for the same language will be implemented on the TX-2. The user would first run and debug his programs interpretively; then debugged subprograms for which faster execution speed is desired could be compiled.

D. Computer-Aided Logic Design

A library of programs has been developed to aid in the LSI processor development. The foundation of this development is a graphics program to assist the logic designer in drawing, simulating, and documenting logic diagrams. Employing the tablet and scope, the designer can draw logic diagrams using standard gates (NAND, NOR, etc., including wired connections that perform a logic function, i.e., wired or), delay elements, wires and input and output pads. Elements of the diagram can be moved, deleted and labeled with an arbitrary character string. A macro facility is available in which a logic diagram can be named, associated with a symbol, then called by name for use in larger diagrams. Macros can be iterated to any depth.

A fundamental feature of this design program is that information about connectivity is not generated during the drawing and editing stages. This makes moving and deleting easy to handle in the data structure and hence fast. An operation called "acceptance" generates the connectivity information and graphically indicates those portions of the diagram that are inconsistent or drawn so that an unambiguous interpretation is impossible.

Once a logic diagram has been completely accepted, the user can write logic values on any set of leads and all logic values implied by the written values will be computed and displayed. If the diagram contains delays or feedback, this simulation is done in increments of one delay time, where all delay elements are assumed to be equal. The most obvious use of simulation is to verify that the circuit does what the designer intended. If mistakes are observed, the diagram can be unaccepted, edited, and reaccepted until the designer is satisfied.

At this point, a variety of programs designed to find test sets for the logic (provided it is combinational) can be called. Test sets, either minimal or near minimal in size, can be computed for the detection of single stuck-at-0 or stuck-at-1 faults. The complete test set for the location of an arbitrary single gate failure can be found. (The theoretical basis for this program was described in the previous Quarterly Technical Summary.) In addition, the tablet can be used to specify constraints on the diagram, and programs can be called to determine whether input vectors exist that satisfy the constraints. These constraints can be arbitrary combinations of logical values and sensitivity conditions.

A diagram and associated data structure, as it exists at any point in the procedure described above, can be saved for future reference. A facility is available for describing existing circuits and inputting, via paper tape or typewriter, their description. While no display is generated, the simulation and test generation programs can be used with typewriter control. All features described are fully operational and will soon be evaluated in an actual design environment.

II. MAGNETIC FILM ENGINEERING

A. Large Capacity Memory

1. LCM-II

We are attempting to extend the batch fabrication techniques used in the construction of the one-million-bit memory in order to build a larger, low-cost memory. The principal approach

is to increase the number of bits on a digit line by lengthening the digit line and increasing the word line density, perhaps by factors of five and four, respectively, which would result in a 20-million-bit memory. To maintain an adequate signal-to-noise ratio, it will be necessary to provide magnetic closure around both the word and digit lines and make digit lines of better quality than those previously made by photolithography and etching.

2. Digit Line Scribing and Testing

Digit conductors 0.006 inch wide on 0.010-inch centers have been generated by scribing completely through the copper into the plastic backing. The magnetic digit keeper of 0.0001-inch permalloy on one side of the digit conductor slightly complicates scribing, since the permalloy is quite hard; however, this apparently can be overcome by taking an extra scribing pass per line. The special scribing machine is being designed for this work, and part of the machine is being built for evaluation.

A tester has been set up for investigations of digit line characteristics and possible testing techniques.

3. Word Line Scribing

Initial experiments have shown that etching of 0.0008-inch-wide word lines on 0.001-inch centers is highly erratic and edge definition is poor. Partial scribing of the copper layer and etching the remainder is also unsatisfactory. Thus, scribing with a diamond tool down to the permalloy layer or even to the glass substrate is being evaluated. A number of 150-line substrates and one 1400-line substrate have been made in this fashion. No copper etching is required, but the permalloy and chrome layers are removed by selective etching. Control of depth of cut and high tool wear are the major problems.

4. Word Decoding Matrix

Use of diode chips bonded directly to word lines to produce simple, inexpensive, word selection arrays is being investigated. Conductive cements, solders, and eutectic bonding are being evaluated as bonding methods, within the constraint of not being able to heat the word substrate above 150°C.

5. Digit Line Flux Closure

A theory of magnetic keeper design predicts that digit line keepers can be made which will make possible an overall increase in signal per unit word line width of as much as six, if both permalloy and plastic-embedded ferrite are used back of and around the sides of 1-mil thick, 6-mil-wide digit lines on 10-mil centers. With 1-μ permalloy on the back, only a factor of three has been demonstrated.

6. Word Line Flux Closure

Experimental nickel-cobalt films of memory quality have been produced by electroless chemical reduction in an amino-borane bath. By suitable bath additions, films with anisotropy fields to 60 Oe have been made. Electroless films from hypophosphite baths show an inexplicably high temperature dependence.

III. SYSTEM PROGRAMMING

A. System Measurement

A system measurement facility has been developed to measure some of the operating characteristics and utilization of the APEX time-sharing system. The measurements are performed within APEX itself; the analyses are performed by user programs afterward. The facility is open-ended in that the variables to be measured are changeable in a relatively simple manner.

The characteristics that are being measured and analyzed are: demand for "computer-time" from the users, use and sharing of public files, and effectiveness of the file-turning strategy. Other measurements are being planned.

B. Circuit Simulation

A computer program has been developed for solving the matrix equation

$$\underline{A}\underline{X} = \underline{B} \qquad (1)$$

when the coefficient matrix $\underline{A}$ is sparse and of large dimension.

The basic idea underlying the program is to construct two tables that specify the nontrivial steps required to solve Eq. (1) by Gaussian elimination. The first table specifies the (nontrivial) steps required to factor $\underline{A}$ into lower and upper triangular matrices $\underline{L}$ and $\underline{U}$. The second table specifies the nontrivial steps necessary to evaluate the produce $\underline{L}^{-1}\underline{B}$ and $\underline{U}^{-1}(\underline{L}^{-1}\underline{B})$. Solution then is effected by interpreting the tables.

The two tables serve as programs. Each row can be regarded as an instruction for a three-address machine. The second, third, and fourth column entries in a row indicate the locations from which operands are to be fetched, and the location in which the result is to be stored. The first column entry specifies an operation to be performed on the operands. Only six distinct operations are required.

Timing runs on the TX-2 computer have indicated that the program is well suited to solving large systems of equations. For example, a set of 100 linear equations can be solved in 150 μsec, after an initial setup (table construction) time of 3 seconds.

The program is one component of a DC circuit simulator that is being developed (see the last Quarterly Technical Summary).

IV. COMPUTER SYSTEMS

A. Display

The new hybrid section for the conic generator was installed in September 1968. Lines and curves drawn with the new hardware at 20 MHz (20 times the former drawing rate) surpass in quality the lines and curves obtainable at 1 MHz with the old system.

B. Consoles

Frames for two new user's consoles were received, and the formica covered work shelf has been ordered. The few required rack modifications are being made and equipment is being installed.

COMPUTER COMPONENTS
GROUP 24

I. PERMALLOY FILMS

A. Determination of Domain Wall Profiles from Lorentz Micrographs

A method has previously been described for calculating the domain wall profile, i.e., the magnetization distribution in a domain wall, given the electron intensity from a defocused Lorentz electron micrograph. This "inversion" procedure has been successfully tested by machine calculations of an artificial wall with a hyperbolic tangent profile. In addition, the effect of a noncoherent electron source has been examined by this method of simulation. These calculations have demonstrated that the inversion procedure works for a range of defocusing distances and for an aperture of electron illumination which are experimentally useful. The inversion procedure has been applied to experimental intensity profiles obtained from microdensitometer traces. The inverted wall profiles seem to be physically reasonable.

II. PEBA MEMORY SYSTEM

A. EuIG Films

Europium iron garnet (EuIG) films have been successfully fabricated on quartz. The process consists of two steps: (1) RF sputtering from an EuIG target in oxygen, and (2) an 800° anneal in a furnace containing one atmosphere of oxygen. X-ray analysis shows the resultant films to be single-phase EuIG while magnetic measurements display a hysteresis loop with coercive force of ~180 Oe.

B. Optical Studies of EuIG

Absorption and magneto-optical rotation have been studied in a single crystal of EuIG. Transitions from the $^7F_1$ to the $^7F_6$ level have been observed which will be suitable for the PEBA memory scheme in which a selected bit is read by thermal pumping from the ground state $^7F_0$ level to the $^7F_1$ level.

C. Optical Cavity Studies

Optical cavities have been made by using total internal reflection for the back mirror and an optical tunnel film as the front mirror. By using a quartz fiber as a field probe, the cavity Q has been measured by varying the angle of incidence of the light. Values of Q ~ 100 are obtained with no effort, although Q ~ 1000 should be readily obtainable.

D. Electron Beam Heating

The frequency response of electron beam heating using a 100-μ-diameter beam and a glass substrate has been found to be in first-order agreement with theory. A careful numerical study is in progress.

III. ELECTRON TRANSPORT

A. Theory of Hot Electron Transport

We have completed a Boltzmann equation analysis of the hot electron relaxation process in metals. One interesting point which emerges is the following. In general, one deals with an initial distribution which is sharply peaked in energy, but with some finite width. As the distribution undergoes electron-electron collisions, it spreads out considerably. The usual method of computing the rate of energy loss for hot electrons involves an assumption that the hot electron distribution is a delta function in energy at all times. We find that this assumption consistently underestimates the rate of energy loss of the distribution.

B. Hot Electron Collection in Metal-Insulator Triodes

The primary mechanism responsible for the inability to collect an appreciable fraction of hot electrons in the metal insulator triodes appears to be due to phonon scattering of the hot electrons as they enter the collector insulating oxide. Even though the electrons lose very little energy per collision (~0.001 to 0.01 eV), the large average change in momentum that results is sufficient to prevent collection. A direct experimental proof of this model is not yet possible. However, collection into single-crystal silicon will be attempted in order to establish that low collection efficiency is not due to some property of the emitter.

PSYCHOLOGY
GROUP 25

I. PROVISIONS FOR MAN-MACHINE INTERACTION ON THE IBM 360/67

A. Mediator and Reckoner

The Mediator of the new design is nearing completion under the current programming contract. It has therefore been decided that the first widely available version of the Reckoner for the 360/67 will use the new Mediator instead of the old.

The computational routines in the new Reckoner will be written in Fortran. As a convenience to the programmer, calls for Mediator services are made through special subroutines called "studs." An initial set of studs has been implemented, their design has been reviewed, and a few minor changes are being made. Work on the design of the Reckoner routines themselves is progressing; from this effort has grown the need for one additional stud. It is apparent that once the studs are available, implementation of the basic Reckoner computational routines will be very rapid.

An initial design has been completed for the process runner. A "process" is a text file which is executed interpretively in such a way that a user can build new computational procedures by concatenating a string of basic operations. The present runner provides for parameterization of process and for designation of temporary variables. It will be augmented to allow for conditional branching within the string of operations and for fielding errors that the user does not wish to have reported to himself. Progress is also being made on the design of several text manipulation routines. These will be used in processes that build and edit processes and data files.

Plans for operating the display scope at the console await delivery and modification of an interface unit at the computer.

B. Documentation for CP/CMS System

The first draft of a primer for new and novice users on the CP/CMS system has been written and is being used experimentally. It is hoped that it will be part of a comprehensive system of documentation directed at users, especially those who are not profoundly familiar with time sharing, or even with programming practices.

The following points appear to be even more important in the implementation of such a system than was originally thought:

(1) The illustrations and examples must be true and accurate. The naive user, if something happens untoward, does not know how to pinpoint his mistrust; he must find the primer itself accurate about what it states.

(2) Most naive users cannot proceed if there is a point that they do not understand, and that they feel to be important (whether it is or not, and whether the understanding of it is important or not).

(3) Users should have real examples to work with while reading the primer, and those examples should be the same as those in the primer.

(4) At least in the beginning, the primer must be extremely and exactly specific about what the user should do; it is very difficult for an author to put himself in the user's place on this point.

(5) Different classes of users have different kinds of needs and different capacities to understand. One should not use examples involving calculus and Fortran programming to show a secretary how to compose a letter on the system, for example.

These points, familiar as they are, are almost not reflected at all in the current documentation of computer systems.

Also, the relation of the primer to the other components of the documentation system (meant very broadly) must be examined experimentally and longitudinally. For example, the primer is meant to bring users up to a level of experience and sophistication to make proper and profitable use of the CP/CMS User's Guide, itself an ambitious document (or set of documents), but one not well adapted to the naive user. Other questions and relationships remain mostly unexplored in a thorough way: how much on-line aid should be available through the system itself? and what form should it take? A paper description of such on-line aid has been formed, but it must bear the test of trial and use. Also, what is the best way to document new facilities as they appear on the system?

C. The Editor System

The different modules of the Editor System are being explored functionally; their operation is correct but very slow. Modifications are being examined both conceptually and experimentally to improve the speed, so as to make it competitive with the current EDIT command. Some thought is being given to a major rewrite of the underlying software components, and a first and tentative inspection is promising.

II. PROVISIONS FOR MAN-MACHINE INTERACTION ON THE TX-2 COMPUTER

A. APEX

Major revisions of the processor-scheduling and core-allocation algorithm in the APEX time-sharing system for the TX-2 computer were completed during the past quarter. The new processor-scheduling algorithm allows a user's task to be split into interactive and noninteractive subtasks. Interactive subtasks are given high-priority scheduling in short bursts, and response is very rapid if the responding program is in core memory. This fast response is available even though the main computation portion of the same user's task is being given a low priority because of accumulated charges for computation and core usage. Supervisor calls are available to allow a user to keep small programs in core and to release them when he no longer requires fast response.

The revisions in the core-allocation algorithm have to do with the way the system measures the core requirements of a user's task during a period of execution, and the rules it uses to decide which programs and data files should be kept in core or brought into core for the next period of execution. The changes have resulted in better information about core usage, as well as better control of the parameters that regulate the allocation strategy.

The adjustment of the many control parameters which affect performance in a time-sharing system requires information about the detailed behavior of the system. During the past quarter, a data collection facility was incorporated into APEX to allow the recording of time, number of active users, core utilization, or any other information of modest bulk at interesting points in the system. The data collection facility is primarily realized with software, and care must be taken

not to load down the overall system with the data collection chore; but experience shows that much useful information can be gathered without noticeable degradation of system performance.

Reliability is always a problem with an experimental facility such as TX-2, and the past quarter has seen more than its share of equipment problems. As a result, a number of small changes have been made in the time-sharing system to allow it to continue operation even though certain equipment is failing occasionally. These changes provide for automatic recording and, where possible, automatic recovery from certain types of failures. Other changes allow the custodians of the system to adjust it to operate in the absence of one or more modules of main memory.

After many delays, the magnetic tape routines for APEX have at last reached the checkout stage. They should be available for use during the next quarterly period.

B. Graphic Reckoner

Initial steps have been taken to determine the feasibility and practicality of constructing a graphic Reckoner. Essentially, the purpose is to give the nonprogrammer a do-it-yourself kit of software for specifying his own forms of interaction with the CRT display and the Tablet. The problem is to determine what compromise between simplicity and generality will be most useful to the nonprogrammer.

The programs that allow the user to draw and to point at parts of pictures will be coherent with other programs in the system. In particular, the outputs of these programs will be Reckoner arrays, and can thus be processed by programs in the Reckoner library. At least at first, LEAP will be used to write the programs for dealing with the Tablet, and the coherent features that have been added to LEAP will provide coherence with other existing programs.

III. HUMAN FACTORS IN ON-LINE COMPUTATION

A new study of human factors in on-line computation has been initiated. It will complement the studies reported in the previous Quarterly Technical Summary by investigating a dimension that had not previously been considered – the variability of delay in the machine's responses. In order to begin this experiment, a new set of 16 problems has been generated, conforming to the criteria mentioned in the previous QTS, thus providing a total of 45 tested problems that can be used in future work. The mean delays in the five conditions of the current experiment are 1, 4, 16, and 64 seconds, but the variability of the delays is much larger, and therefore more realistic, than in the previous experiments. The distribution of delay times is a Chi-square distribution with four degrees of freedom, which is equivalent to the convolution of two exponential distributions.

A Technical Note on the results of the previous three experiments is being prepared.

IV. HUMAN INFORMATION PROCESSING

A. Decision Making Near the Visual Threshold

The previous Quarterly Technical Summary reported the construction of an automatic apparatus for an extended study of the temporal characteristics of processes that mediate visual detection. The experiments are concerned with the frequency and latency of response in detecting stimuli that contain two successive flashes. Preliminary results from the experiments that are now in progress show that the speed of response to an initial low-energy flash can be increased by the subsequent occurrence of a high-energy flash. This interaction is being investigated further.

COMPUTER SYSTEMS
GROUP 28

COMPUTER CENTER DEVELOPMENT

During the past quarter, substantial effort was invested in merging Lincoln's version of the CP/CMS Time-Sharing System with the version operated by the IBM Cambridge Scientific Center. Although each system still retains local improvements and special features, they are essentially compatible. The principle reason for this merger was to allow Lincoln easy access to the continual updates and improvements provided by the Scientific Center. Among those immediately available is a feature referred to as the "dedicated multiplexor." This capability permits the definition of various low-speed devices on the multiplexor channel of a user's virtual machine, making possible such things as the attachment of a low-speed data collection line to a given user. Another capability provided by the merged system is that of operating the IBM OS/360 Batch Monitor under CP as one of the users. While the latter is not intended for regular or efficient batch running, it is a very useful tool for systems programmers working on OS.

As the demand for time-sharing terminal hours continues to grow, more attention is being given to system control and accounting features. Short of operating CP/CMS on both sides of the duplex 360/67 computer, there will be no significant increase in total capacity in the near future. Therefore, it will probably become necessary to schedule the use of terminals in order to distribute available time in an equitable and efficient manner. To do this, the system operator will need to have current and immediate knowledge of such things as who is on the system, what lines are in use, and the length of time a user has been running. Features to provide this kind of information and the additional operator controls needed to implement a schedule are already under development.

Other continuing work also aimed at getting more from the system includes the improvement of the input/output activity of the language processors and the provision for tape capability in the batch operation. During the past quarter, work was also completed on a dual user dictionary designed to minimize losses to files caused by sudden failures of the system. The capacity of each user's files was also increased by making more complete use of the disk format.

Lincoln's batch monitor, IBM-OS/360, has been undergoing both a long-range and a short-range examination. Since the major part of the Laboratory's production work continues under OS, there has been the usual activity of maintenance and minor improvement. More recently, work has begun on implementing the latest version of the system released by IBM (15/16). This is the short-range examination. The long-range look has been a consideration of the two multiprogrammed operating systems provided by IBM. Each, in its various configurations, has something to offer, but each also has some impact on existing production programs. An investigation of the future direction of OS/360 continues.

The data collection capability of the Lincoln-developed multiprogramming system, LLMPS, was used in support of the September launch of Lincoln Experimental Satellite LES-6. Data sent by telephone line from Cape Kennedy were received by LLMPS running on the 360/40 computer.

After minor editing, the data were distributed automatically to seven data terminals in a control center within the Laboratory. Although this activity taxed the power of the computer, it was possible to maintain a satisfactory flow of printing, card punching, prestoring, and similar off-line utility work throughout the several days that the LES data were being handled. Consideration is being given to moving this application onto the 360/67 under CP/CMS now that the dedicated multiplexor device capability is available.

RADIO PHYSICS
DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 August through 31 October 1968. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary and the Quarterly Letter Report to ARPA.

S. H. Dodd
Head, Division 3

M. A. Herlin
Associate Head

DIVISION 3 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1968

PUBLISHED REPORTS

Journal Article*

JA No.			
3145	Observations of Galactic OH Emission	J. A. Ball M. L. Meeks	Astrophys. J. 153, 577 (1968)

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
3268	Measurements of the Afternoon Radio Aurora at 1295 MHz	R. E. Newell † W. G. Abel	Accepted by J. Geophys. Res.
MS-2354	Observations of Orion A at 15.5 GHz	M. A. Gordon	Accepted by Astron. J.

Meeting Speeches ‡

MS No.			
2329	Radar Studies of Venus at 3.8 cm Wavelength	J. V. Evans T. Hagfors R. P. Ingalls D. Karp W. E. Morrow § G. H. Pettengill A. E. E. Rogers I. I. Shapiro § W. B. Smith § F. S. Weinstein	International Physics of the Moon and Planets Meeting, Kiev, Russia, 15 – 22 October 1968
2383	Interferometric Observations of Interstellar Hydroxyl Clouds of Extremely Small Size	J. M. Moran, Jr.	NEREM, Boston, 6 – 8 November 1968
2444	Radar Surveys of the Solar System	J. V. Evans	American Philosophical Society, Philadelphia, 14 – 15 November 1968

* Reprints available.

† Author not at Lincoln Laboratory.

‡ Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

§ Division 6.

SURVEILLANCE TECHNIQUES
GROUP 31

I. SUMMARY

Group 31 conducts the research program of Lincoln Laboratory's Millstone and Haystack radio/radar research facilities.

At Millstone, work continues on the careful evaluation and improvement of the antenna and tracking system in preparation for the anticipated radar propagation program. The Thomson scatter program has emphasized measurements made during passes of pertinent instrumented satellites. An intensive short program of precipitation and clear air scattering studies requested by the DoD was completed successfully, using both the Millstone L-band radar and the Haystack radiometers.

Modifications to the Haystack planetary radar were completed to permit the NASA dual-polarization radar studies of the moon to begin. Scheduled operations with the planetary radar resumed in late October. An X-band very long baseline interferometer (VLBI) was instrumented using Haystack and the 140-foot Green Bank antenna of the National Radio Astronomy Observatory (NRAO). VLBI fringes at 3.8 cm were observed for the first time when the data were processed at Haystack.

II. SPACE SURVEILLANCE TECHNIQUES

A. Tracking Studies

With the cessation of satellite tracking activities at the station, further refinements of the Millstone Hill computer-aided tracking program (MHESPOD) have come to a virtual halt. At present this program steers the antenna and determines the target orbit in real time based upon previously accepted range, Doppler and antenna-position information. One new feature is the use of the monopulse information directly in the program rather than just to position the antenna on target. Correspondingly, a novel technique is being tested to calibrate the monopulse error response while the antenna is still in autotrack mode. Preliminary tests have been encouraging. Further evaluation of this technique, especially at low elevation angles, awaits completion of receiver and transmitter tests now in progress.

Other preparations for a contemplated program which will study the effect of various propagation phenomena on precise tracking have included a careful evaluation of the antenna with respect to boresight shifts due to structural deformations, servo parameters and limitations, and data pickoff improvements.

TRW Systems, Incorporated, have requested test cases and diagnostic assistance to check out their own modifications to MHESPOD. Such assistance led us to discover and correct a defect in the program; thus, the cooperation was mutually beneficial.

B. Auroral Studies

This period was wholly devoted to the analysis of radar data gathered during January, February and March of 1968. One new result is apparent thus far: range information derived from transmissions with 10- and 50-μsec pulse lengths shows two general categories of echoes. One consists of two or more horizontally stratified layers, while the other comprises a number of discrete patches.

III. PLANETARY RADAR

A. Planetary Radar System

The planetary radar system underwent major changes during this quarter for outfitting as a lunar pulse radar. The transmitter was fitted for a short pulse duplex mode providing capability to transmit pulse widths of 10 μsec at repetition periods of 20 to 50 msec. The required T/R protection equipment was installed and checked out. The receiver was expanded to two channels to receive both circularly polarized senses of the reflected signals. Waveguide installations were completely reworked, and a dual-channel maser amplifier was installed in a single liquid-helium dewar. The primary or left circularly polarized receiving channel performance now exhibits a 43°K system temperature, a significant improvement over the 55° to 65°K range previously obtained. The transmit or right circularly polarized receiving channel system temperature is close to 85°K, reflecting the extra waveguide loss in this channel associated with transmitter and T/R components. The liquid helium boils away in less than 15 hours, compared to the 18 hours previously with the single maser configuration. Additional work on the maser may lengthen this time.

A major effort was directed at making the various radar subsystems more efficient and foolproof in operation. Improvements include mechanization of the maser tuning procedure, provision for remote operation of the receiver at a central control console, and redesign of some A-to-D conversion equipment at the data processing computer interface to permit higher speed data sampling. Forthcoming lunar experiments require that both receiver polarizations be processed at 10-μsec range intervals and if possible as finely as 3 μsec.

B. Lunar Studies

The modified planetary radar box was mounted on the antenna for the first time this quarter on 21 October for a four-week observing period. Initial tests of the lunar mode proved successful, and the program of lunar observations began at once. The goal is to map and analyze maps of the entire visible surface in both transmitted and orthogonal polarizations. NASA partially funds this program under Contract NAS 9-7830.

C. Planetary Studies

Scheduled planetary observations resumed on 25 October with range measurements of Mercury and Venus.

Mercury spectral data were examined to determine a revised scattering law. This law permitted a re-analysis of earlier range data on Mercury which enhanced significantly the signal-to-noise ratio of the processed echo.

IV. THOMSON SCATTER

Observations of three types have been made during the reporting period:

(1) Regular UHF (vertical) measurements over a 24-hour period,
(2) UHF (vertical) drift measurements over a 24-hour period,
(3) L-band (oblique) measurements over an 18-hour period.

In addition, a number of short observing periods were scheduled to coincide with passes of the satellites Alouette II or OGO IV. The Alouette passes permit a comparison of Thomson scatter and in-situ (Langmuir probe) determinations of electron temperature. Measurements made during OGO passes will permit calibration of the on-board ion mass spectrometer from our determination of electron density.

A new computer program has been completed and is in use to analyze a two-year backlog of spectral data recorded on punched tape. The program recognizes virtually all the malfunctions encountered in the old (ANDIREC) spectrum analyzer and generates estimates of electron and ion temperature as good as those obtained by careful hand analysis. Work is under way to complete a similar program to handle the spectral data produced by the new analyzer (RETIAS).

V. RADIOMETRIC TECHNIQUES

A. Instrumentation

Most radiometric experiments conducted at Haystack during this quarter used the standard equipment of the radiometer box (R-box). There were, however, two exceptions: the X-band very long baseline interferometry (VLBI) experiment and the L-band Jupiter occultation observations.

The X-band VLBI utilized the 120-foot Haystack antenna and the 140-foot antenna of the NRAO at Green Bank, West Virginia. For this experiment an early Haystack parametric amplifier was installed in the R-box. This installation permitted step-tuning of the operating frequency by means of logic circuits controlling varactor bias and pump power. The objective was to achieve synthetic wideband operation and thus to measure unambiguously difference in arrival time between the two antennas.

The L-band occultation observation required two receivers arranged to measure polarization of the Jupiter emission. The second receiver was borrowed from Millstone.

Work continues on the 100-channel digital correlator. This unit, with a maximum sampling rate of 50 MHz, will not only provide a new order of capability for spectral-line work, but, when connected for use as a cross correlator, will greatly ease the load on the general purpose computer when processing VLBI data.

B. Radio Astronomy

During the period from 30 September through 15 October, the Haystack antenna and the 140-foot antenna of the NRAO (Green Bank, West Virginia) operated as a VLBI. Observations were made at 4 and 18 cm. The principal objectives of this experiment were:

(1) Determination of the angular size of newly discovered OH sources that emit strongly at 1612 MHz,

(2) Initial trials of the so-called time-delay interferometer that permits observations over an extended bandwidth,

(3) Determination of the baseline joining the two terminals.

The data collected during these observations are being analyzed at Haystack, and results to date indicate success in fulfilling objectives (1) and (3). The time-delay interferometer system could not be fully tested because of difficulties with the parametric amplifier and bad weather conditions. However, interference fringes have been detected at 4-cm wavelength for the first time in VLBI experiments.

The sun was mapped at 2-cm wavelength on 20, 21, and 22 August. Two flares were observed on 21 August. The long term programs for observing time variations in radio emission from quasars and peculiar galaxies and the single-antenna measurements of OH sources have continued. We have begun a search for pulsar signals with the 4-cm masers and data processing systems of the planetary radar system.

An analysis of recombination line observations made earlier this year with the planetary radar box led to new information on the internal structure of H II regions. The technique consisted of observing the 94α (7.792871 GHz) line of hydrogen at 21 points in a grid (5 × 5 with corner points omitted) over the nebula NGC 2024. This grid, with spacings of half-beamwidth intervals, permits contour maps to be made of quantities calculated from the line observations. The maps show the spatial distribution of electron temperature and density, of gross kinematics and of internal motion over the nebula. The technique produces information fundamental to theories of stellar formation that cannot be obtained with optical methods.

An attempt was made on 19 October to observe the occultation of Jupiter by the Moon. The object of this experiment was to determine the centroid of Jupiter's radiation belts and thus of its magnetic field. The data were unfortunately marred by interference.

VI. METEOROLOGY

This work is a cooperative effort which serves both the Laboratory's Space Communications and Radio Physics programs.

A. Rain Observations

This year's rain measurement program is now complete, and data processing is in progress. The program included simultaneous measurements of rain brightness temperature at 8 and 15 GHz with the Haystack radiometer system, rain backscatter cross section per unit volume with the Millstone L-band radar, and bistatic scattering cross section per unit volume for scattering angles between 0 and 180 degrees with an X-band transmitter in Avon, Connecticut and the Westford Communications Terminal. These measurements permit study of rain's effect on interference between two ground stations operating at the same frequency in the SHF band and are part of our continuing study of the meso-scale structure of rain.

The data show that rain can be important in transmitting interference at frequencies within the SHF band. The highest recorded signal levels obtained with the forward scatter system occurred for pointing angles away from the great-circle path and were caused by heavy rain. For four days during the two-week measurement period, rain and several severe thunder showers were observed. The bistatic data for these thunderstorms consistently showed high signal levels.

The method of analysis will be to compute the expected bistatic scattered signal level using the simultaneously measured radar data and to compare the measurements with the predictions. In this way the method of estimating the rain-scattered interference fields, based on measured radar data, will be validated.

B. Clear Air Measurements

Clear air scattering was observed by both the Millstone L-band radar and the forward scatter link. These measurements were made during the two-week observations period mentioned above at times when rain did not occur. The objective of this program is to find a technique for estimating scattered field strengths of the turbulent layer for transhorizon scatter links. These measurements are similar to those of the Wallops Island – Westford link reported earlier. The scattering regions have lower altitudes for this link, and other transhorizon propagation mechanisms may contribute to the received signal.

An initial analysis shows that the Wallops Island – Westford data are consistent with a model of thin turbulent layer scattering. Geometry prohibits simultaneous radar and forward scatter measurements of the same volume of space. However, both radar and forward scatter data agree on the position of the layer heights and on the order of magnitude of the layer strength when radiosonde data show the atmospheric structure to be nearly the same for both observation volumes.

RADAR
DIVISION 4

INTRODUCTION

The General Research activities in Division 4 for the period 1 August through 31 October 1968 consist of work on diode-using devices, wideband antenna feeds, computer-aided design, microwave circuits, and millimeter technology. The major activities of the Division are in the RDT, PRESS, RSP, and MTI Radar programs, which are reported on separately.

H. G. Weiss
Head, Division 4

DIVISION 4 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1968

PUBLISHED REPORTS

Technical Note

TN No.				DDC and Hayden Nos.
1968-32	Small Obstacle and Aperture Theory	J. M. Ruddy	29 August 1968	DDC* H-900

Journal Article†

JA No.			
3215	High-Power Microwave Power-Combiner Using a Series-Parallel Array of Diodes	W. J. Getsinger	Proc. IEEE 56, 1217 (1968)

* * * * *

UNPUBLISHED REPORTS

Journal Article

JA No.			
3356	A Millimeter-Wave Lunar Radar	J. J. G. McCue	Accepted by Microwave J.

* Not yet assigned.

† Reprints available.

MICROWAVE COMPONENTS
GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave needs of the Laboratory. Contributions are made through the study of the problems of solid-state diode-using devices, the development of techniques for computer design of microwave devices, studies of very-high-gain antennas and antenna feeds, operation of a high-power microwave laboratory, and participation in a millimeter-wavelength program.

II. DIODE-USING DEVICES

A. Diode Measurements

Theoretical analysis of resistive decoupling for the large radial-line diode-measuring cavity indicated the possibility of considerably reduced detuning errors. Detuning errors are the result of reflections in the waveguide and coaxial lines leading to the radial-line cavity.

A small, low-impedance resistive disk, flush with the inner surface of the radial-line cavity, will provide frequency-independent decoupling of the cavity from the input lines.

An appropriate resistive disk has been designed, and a purchase order has been placed for a number of them. It is intended that the existing 30-inch copper radial cavity will be modified to incorporate one of these decoupling disks. If a significant improvement in measuring accuracy is achieved, the design of a 24-inch aluminum radial cavity will be considered.

B. Power Combiners

Construction of the 15-diode power-combining doubler has been completed, and the combiner is now in the final stages of assembly. It will use specially made diode columns, each column consisting of five packaged diodes and cooling fins assembled as a unit. These columns were designed at Lincoln Laboratory but were constructed by a nearby diode manufacturer.

New tuners and diplexers of lower loss than those used previously have been designed and constructed. A test setup has been assembled, tuned, and calibrated. Electrical tests are expected to begin in the near future.

If the power combiner operates as expected, it will deliver about 200 watts CW at 1020 MHz by converting power at 510 MHz with about 60 percent efficiency.

C. Low-Noise Balanced-Diode Mixers

The performance characteristics of Schottky Barrier mixer diodes, which have been purchased from various diode manufacturers, have been determined on the 1-MHz bridge and on the 3-GHz modified Mavaddat diode bridge. A number of reasonably matched diode pairs have been found for use in the balanced diode mixer.

A new diode test jig for the measurement of diode characteristics at 10 GHz using a modified Mavaddat technique has been fabricated. The diodes previously tested at 1 MHz and 3 GHz will now be measured at 10 GHz.

A preliminary balanced-diode mixer has been set up at S-band and has yielded a conversion loss of approximately 3 dB, including approximately 1.8 dB of filter and circuit loss. This mixer is being improved at the present time and noise figure measurements, as well as conversion loss measurements, will be made.

III. WIDEBAND ANTENNA FEEDS

Additional work on the rectangular multimode horn reported previously has shown that the beamwidth in the 45° plane cannot be made equal to the E-plane and H-plane beamwidths when the ratio of the higher-order modes to the dominant mode is large. This is due to the relatively small effect of the higher-order modes on the 45° plane.

Since the use of the horn as a wideband feed requires a rather large higher-order mode ratio, the 45° beamwidth will always be somewhat smaller than the principal-plane beamwidth. The maximum VSWR of the rectangular horn was 1.45 over the 4- to 5.8-GHz band, and 1.1 over the 7.75-to 8.15-GHz band without impedance matching of any kind. The bandwidth limitation at the higher frequency is due to pattern deterioration.

Calculations have shown that a rectangular multimode horn with −30 dB sidelobes and cross polarization in all planes is possible. The moderate higher-order mode ratio which is required makes it possible to equalize the beamwidth in all planes. Such a horn is an improvement over a square multimode horn which uses only E-plane mode control and consequently has 23-dB sidelobes in the H-plane. However, unlike the rectangular horn, the square horn has dual polarization capability. The bandwidth of both horns is comparable, since both are limited by the E-plane mode generator.

IV. COMPUTER-AIDED DESIGN OF MICROWAVE CIRCUITS

The reason for using large digital computers in microwave design is that a large amount of useful information is produced in a very small amount of time. Using conventional batch processing, an engineer can obtain more data in one day from a computer than he could in a week by hand-computation techniques. It is now becoming apparent that by using a sophisticated general-purpose program on a time-shared system, the engineer might reduce design time from a day to 30 minutes.

The dramatic reduction in time and effort involved in a design problem leads to a different point of view on the part of the design engineer. He is able to produce a better design because he is able to learn more about the effects of parameter variation while on the computer, rather than by doing these experiments on the bench. In addition, he is able to handle not only more problems but also more difficult problems. The new point of view includes these aspects, but the basic idea is that problems will now be approached from the outset in terms of solution by computer. In most cases, this means that the problem is set up emphasizing numerical techniques over analytical techniques.

A. Automatic Parametric Amplifier Design

About a year and a half ago, a computer program was completed which allowed one to calculate the inner dimensions of a parametric amplifier of predetermined topology on the basis of desired center-frequency performance. A second computer program predicted the response of this paramp over a wide frequency band. Some X-band paramps were built with computer-determined dimensions and were found to operate substantially as predicted, with no cut-and-try needed on the test bench.

Recently, the two programs were updated by modifying them (1) to operate on a time-share system, and (2) to provide graphical output.

The design program generates a properly scaled and fully dimensioned sketch of the paramp. The performance program generates curves of gain vs frequency for the paramp designed by the first program. The performance program also allows the operator to investigate changes in paramp performance for various parameter changes, just as a technician would investigate changes in performance of an actual paramp on the test bench.

The graphic output can be observed and changed by the operator while running the program. This is accomplished by using an IBM 2250 graphic display console. The operator is also able to request a permanent copy (hard copy) on paper by using the Stromberg-Carlson 4020.

These results demonstrate that computer programs can be made to provide dimensions automatically for a complex microwave component on the basis of required performance, and to present these results as a usable design sketch. Also, the performance of such a proposed design can be investigated in real time for parameter changes initiated by the operator. No additional work on these programs is anticipated.

B. Automatic Analysis of Microwave Circuits

A major part of microwave circuit design requires (1) setting up equations according to an equivalent circuit, (2) programming them, and (3) calculating performance.

An on-line microwave circuit analysis program now being worked on automatically takes care of these three functions once the circuit has been described to the computer from a remote time-shared terminal.

At present, the program will provide frequency analysis of a single cascade of two ports. The cascade can be made up of a variety of two-port sections which are available to the operator. A range of driving-point and transfer-function measurements are at the option of the user. Also, the user can change both the type and the element values of the sections making up the cascade.

This program, which is denoted GCP (general circuit parameters), will be improved to allow for a multiplicity of cascades interconnected in various ways.

V. MILLIMETER-WAVELENGTH PROGRAM

The conversion of the 35-GHz lunar radar to dual circular polarization was completed about 1 August 1968. Observations on the moon showed echoes in both channels, but in the "expected" channel they were about 10 dB weaker than before the changeover. A thorough search for loss in the new plumbing revealed no anomalies. A check on other possible sources of trouble showed that the local oscillator spectrum had failed because of overheating and eventual failure of a power supply in one of the 5-MHz-to-35-GHz multipliers. The multipliers have been returned

to the manufacturer for redesign of this power supply, replacement of the varactors that its failure damaged, and retuning. Since construction of the radar is completed, work on it has ceased. When the multipliers have been returned, there will be one more measurement of the reflectivity of the moon.

The phenomenon ascribed in the last Quarterly Technical Summary to atmospheric refraction of millimeter waves has been observed on two new occasions. The circumstances and behavior of the phenomenon seem to confirm that it is caused by refraction in the atmosphere, presumably by a humidity gradient.

ENGINEERING
DIVISION 7

INTRODUCTION

The Engineering Division's support of the General Research Program is evidenced principally by its developmental work in integrated circuits and its engineering of electromechanical devices for the research facility at Haystack and Millstone Hills. New techniques for depositing dielectric materials, custom metalization, and the development of ideas for computer-aided layout are all active phases of the integrated circuit program. Concurrently, the facilities for fabricating such circuits are being upgraded through the construction of required clean-room space.

At Haystack, work continues on the attempt to achieve reliable dual maser units which will provide cryogenic temperatures for extended periods of time, while at Millstone the principal engineering efforts are devoted to the installation of the mirror mounts for the new optical tracker and to the design of a control system for pointing the mirrors.

J. F. Hutzenlaub
Head, Division 7

MECHANICAL ENGINEERING
GROUP 71

I. HAYSTACK CRYOGENICS

Tests are continuing with dual simulated masers in closed cycle refrigerators. During a recent cool-down, all systems operated normally for thirty hours at which time the vacuum in the cryostat started to deteriorate. Subsequent diagnosis indicated that there was a helium gas leak in the process piping. Cryostats were interchanged and a duplicate cool-down attempted which proved futile due to a drive chain failure in the warm engine. The engines have now been replaced with a more rugged design and the system is being readied for further tests.

II. SOLID STATE RESEARCH (High Pressure Techniques)

This quarter has been devoted to a re-evaluation and improvement of high pressure generating equipment and techniques. Three aspects are being evaluated:

Efficiency
Hydrostatic capacity
Versatility.

Efficiency is a function of load and pressure, which, in turn, are functions of volume reduction (ΔV). Where ΔV is not limited theoretically, such as in straight piston and cylinder devices, superpressure is not possible because the stresses involved will exceed the maximum strength of the materials. Where ΔV is limited by angular design configurations of the high pressure equipment, such as in conical anvil systems, the load per unit pressure will reach undersired proportions; for example, at superpressure conditions one may have to double the load to yield a slight increase in pressure. It is correct to say that there is a maximum pressure condition for every design, and each design serves its own specific needs. To develop a device with a much broader range of use is the purpose of this investigation.

Specimen containers which are to be subjected to high pressure are usually enclosed in a pyrophyllite mass. Small geometrical changes in the assembly of the pyrophyllite pressure transmitter may result in a change in the efficiency of the equipment. They can also lead to a change in the hydrostatic capacity of the pressure transmitter which will yield uniaxial stresses and undesirable shear forces in the specimen. A combined modification of pressure transmitters and equipment may lead to a significant improvement in pressure-generating techniques.

Versatility concerns itself with high as well as low temperature applications and measurements at superpressure conditions. These investigations are continuing.

III. CO_2 LASER RADAR

The designs for the three pedestals supporting mirror mounts at the Millstone Hill laser installation are now 95 percent complete. The two fixed-mirror mounts have been completely assembled and are ready for installation at the site. Anchor bolts have been placed at ground

level inside the base of the concrete tower to hold the lower fixed-mirror mount, and the top of the tower is being modified to receive the second fixed-mirror mount.

The third pedestal which supports the tracking mirror mount has also been completely assembled. The declination axis assembly of the tracking mirror mount is now in the final assembly stage and will be servo-tested in advance of the completion of the elevation axis assembly, which is still being fabricated.

Design of the television tracking system has been finalized and the detail design of component parts is in process.

The granite tables which will hold the various lasers and auxiliary equipment in the system have been installed on the supports and are now being leveled and brought to their proper heights. The 3:1 beam expander has been completed and is now being optically checked.

COMPONENT DESIGN AND DEVELOPMENT
GROUP 73

INTEGRATED CIRCUIT FACILITY

The Integrated Circuit Facility has continued in its research and development of materials and processes and in the application of these to specific programs or tasks within Lincoln Laboratory.

The deposition of dielectric material by thick film techniques using devitrified glass has been successful and is now being applied to capacitor elements and to methods for providing multilayer metalization in conventional hybrid circuits. Sputtered silicon dioxide for thin film applications, when the dielectric coatings range in thickness from a few hundred angstroms to several thousand angstroms, is under development. The present yield of the sputtered dielectric material must be improved before it can be conveniently employed in circuit and component application.

The fine line (one micron or less) work that has become a major part of the Group 73 program is progressing rapidly because of the availability of computer-aided layout programs and the excellent resolution of the D. W. Mann pattern generator. In addition, the recent development of etching by back-sputtering techniques has significantly improved the fine line metalization while reducing the process variables that are common to chemical etching methods.

A cooperative program with MIT and Division 4 on the use of a scanning electron beam microscope for high resolution exposure of photoresist is in progress. Improvement in the eventual line resolution should be more than an order of magnitude and will extend the current limits of fine line metalization work.

The beam lead substrate work is progressing satisfactorily, and several large monolithic chips with 32 peripheral pads have been assembled using this technique. The chips are presently located and aligned manually prior to the bonding operation, and although this presents no major difficulties, it appears desirable to develop some special fixturing to reduce the alignment time. The beam lead substrate technique is being applied to high frequency applications as well as to monolithic arrays, and this may become one of the important applications for this technique.

The equipment installation and checkout for the semiconductor area have been recently completed, and a limited processing of semiconductor devices and components relating to various laboratory programs will be initiated shortly. Limited yield of these semiconductor elements is expected until the operation is located in an adequate, clean environment.

A program of custom metalization of commercial monolithic chip arrays has been initiated as an adjunct to the semiconductor program. By employing custom metalization at the cell level for logic and signal interconnection, any of the available standard commercial monolithic arrays can be made into special or custom networks for Lincoln Laboratory system designers.

A number of direct applications illustrate the extent of the integrated circuit program. Surface wave transducers have been fabricated using automated layout programs and sputter etching

techniques with good results. Operation of the transducers at 400 MHz with moderate insertion loss has recently been achieved. The application of the beam lead substrate technique to logic circuits containing monolithic chips and to very high frequency circuits has been demonstrated. Several 256-bit read-only memory chips have been assembled in beam-leaded substrates with minimum problems. Microwave networks using thick film techniques rather than thin film to obtain lower cost fabrication are under development, and initial results are encouraging.

PHYSICAL PLANT ENGINEERING
GROUP 75

I. BUILDING E EXTENSION (Integrated Circuit Facility)

The addition of approximately 16,000 square feet of floor space onto Building E is about 60 percent complete. The first phase of construction includes the basic building structure, utilities, and a class 100 clean room. Work on the 900-square-foot class 100 clean room has just begun. Construction work on Phase I is thus expected to be completed on 1 February 1969.

Phase II will include the installation of a 1600-square-foot class 10,000 clean room, and the division of the remaining 8000 square feet of main floor area into laboratory space.

The lower level of the building will house the mechanical equipment required for the operation of the two clean rooms. This area will also include the waste disintegrator, electrical switchgear, and some 1400 square feet of storage space.

II. BUILDING J MODIFICATION

Phase I of the Building J modification was completed on 15 September 1968. This work included installation of new chilled water fan coil units, associated duct work, noncombustible ceiling, fire detection systems, and an automatic sprinkler system.

Phase II work involves the addition of approximately 6000 square feet of floor space. This includes the installation of a raised floor system, air conditioning, lighting, noncombustible ceiling, fire detection system, extension of the automatic sprinkler system, and miscellaneous modifications to the existing area.

Approximately 66 percent of the floor space will be occupied by 15 November 1968 and the balance should be completed by 1 January 1969.

CONTROL SYSTEMS
GROUP 76

I. HAYSTACK

A new motor was installed on the hydraulic test stand to evaluate its suitability as a possible replacement for the existing Haystack antenna drive motors. This motor is driven by a variable displacement pump rather than by one of the servo valves used in the present system. Ability of the pump-motor combination to handle the required large load inertia has been confirmed; satisfactory performance as part of a closed loop system remains to be demonstrated.

II. MILLSTONE OPTICAL TRACKER COMPLEX

Design of all circuitry necessary for interconnecting the two mounts at the optical tracker complex with the digital computer used for pointing and coordinate transformations was completed. Buffer equipment required to read Haystack and Millstone radar data into the computer was designed. Manufacture and assembly of all units is about 90 percent complete. Interconnection diagrams were prepared, but site installation will be delayed until checkout of all equipment has been completed at the Laboratory.

The laser radar mount was assembled at the Laboratory, and mechanical tests leading to the determination of the required servo compensation were begun. Initial emphasis is upon establishing satisfactory rate loop performance.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 August through 31 October 1968. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 August through 15 November 1968

PUBLISHED REPORTS

Journal Articles*

JA No.			
3048	Performance Characteristics of Thermomagnetic Devices Involving Graded Mass and Gap. I. Generators	J.M. Honig B. Lax	J. Appl. Phys. 39, 3549 (1968)
3195	Electrical Properties of Ti_2O_3 Single Crystals	J.M. Honig T.B. Reed	Phys. Rev. 174, 1020 (1968)
3206	Partial Pressure of $Se_2(g)$ in Selenium Vapor	R.F. Brebrick	J. Chem. Phys. 48, 5741 (1968)
3219	Tuning of PbSe Lasers by Hydrostatic Pressure from 8 to 22 μ	J.M. Besson† W. Paul† A.R. Calawa	Phys. Rev. 173, 699 (1968)
3223	Upper and Lower Bounds for the Intermediate-Coupling Polaron Ground-State Energy	D.M. Larsen	Phys. Rev. 172, 967 (1968)
3255	Intermediate-Coupling Polaron Effective Mass	D.M. Larsen	Phys. Rev. 174, 1046 (1968)
3273	Optical Heterodyne Detection at 10.6 μm of the Beat Frequency Between a Tunable $Pb_{0.88}Sn_{0.12}Te$ Diode Laser and a CO_2 Gas Laser	E.D. Hinkley T.C. Harman C. Freed	Appl. Phys. Letters 13, 49 (1968)
3276	Far-Infrared Photoconductivity in High-Purity Epitaxial GaAs	G.E. Stillman C.M. Wolfe I. Melngailis C.D. Parker P.E. Tannenwald J.O. Dimmock	Appl. Phys. Letters 13, 83 (1968)
3280	Pressure-Induced Structural Changes in the System $Ba_{1-x}Sr_xRuO_3$	J.M. Longo J.A. Kafalas	Materials Res. Bull. 3, 687 (1968), DDC 674791
3303	Quenchable Effects of High Pressures and Temperatures on the Cubic Monoxide of Titanium	M.D. Banus	Materials Res. Bull. 3, 723 (1968)
3306	Band Structure and Electrical Conductivity of NiO	J. Feinleib D. Adler†	Phys. Rev. Letters 21, 1010 (1968)

* Reprints available.

† Author not at Lincoln Laboratory.

JA No.			
3316	Preparation of $\{A_3^{2+}\}$ $[Te_2]$ (B_3^{2+})-Garnets	H. M. Kasper	Materials Res. Bull. 3, 765 (1968)
MS-2249	Ultraviolet and Infrared Pumping of OH Molecules	M. M. Litvak	Interstellar Ionized Hydrogen, Y. Terzian, ed. (W. A. Benjamin, Inc., New York, 1968)

UNPUBLISHED REPORTS

Journal Articles

JA No.			
3082	Symmetry of the Ground Level of a Hamiltonian	W. H. Kleiner T. A. Kaplan	Accepted by J. Math. Phys.
3264	Magneto-Optical Properties	J. G. Mavroides	Accepted as a chapter in Optical Properties of Solids, F. Abeles, ed. (North-Holland, Amsterdam)
3267	Spherical Model as the Limit of Infinite Spin Dimensionality	H. E. Stanley	Accepted by Phys. Rev.
3286	Homogeneity Ranges and Te_2-Pressure Along the Three-Phase Curves for Bi_2Te_3(c) and a 55-58 at % Te, Peritectic Phase	R. F. Brebrick	Accepted by J. Phys. Chem. Solids
3295	Low Level Coherent and Incoherent Detection in the Infrared	R. J. Keyes T. M. Quist	Accepted as a chapter in Semiconductors and Semimetals, Vol. VII
3300	Metallic Inclusions and Cellular Substructure in $Pb_{1-x}Sn_xTe$ Single Crystals	J. F. Butler T. C. Harman	Accepted by J. Electrochem. Soc.
3311	Effect of Pressure on the Magnetic Properties of MnAs	N. Menyuk J. A. Kafalas K. Dwight J. B. Goodenough	Accepted by Phys. Rev.
3312	Effect of the Molecular Interaction on the AC Kerr Effect: Possibility of a Field-Induced Phase Transition	J. Hanus	Accepted by Phys. Rev.
3313	Exact Solution for a Linear Chain of Isotropically Interacting Classical Spins of Arbitrary Dimensionality	H. E. Stanley	Accepted by Phys. Rev.
3326	Characterization of Phases in the 50-60 at % Te Region of the Bi-Te System by X-Ray Powder Diffraction Patterns	R. F. Brebrick	Accepted by J. Appl. Crystal.

JA No.			
3329	Isolation of Junction Devices in GaAs Using Proton Bombardment	A. G. Foyt W. T. Lindley C. M. Wolfe J. P. Donnelly	Accepted by Solid State Electron.
3336	Epitaxially Grown Guard Rings for GaAs Diodes	C. M. Wolfe W. T. Lindley	Accepted by J. Electrochem. Soc.
3345	Optical Properties of Mg_2Si, Mg_2Ge and Mg_2Sn from 0.6 to 11.0 eV at 77°K	W. J. Scouler	Accepted by Phys. Rev.
3348	Temperature Dependence of Raman Linewidth and Shift in α-Quartz	A. S. Pine P. E. Tannenwald	Accepted by Phys. Rev.
3350	The P-T Phase Diagram of InSb at High Temperatures and Pressures	M. D. Banus M. C. Lavine	Accepted by J. Appl. Phys.
3353	$LnCrTeO_6$ – A New Series of Compounds Based on the $PbSb_2O_6$ Structure	H. M. Kasper	Accepted by Materials Res. Bull.
3371	Bismuth Doped $Pb_{1-x}Sn_xTe$ Diode Lasers with Low Threshold Currents	J. F. Butler T. C. Harman	Accepted by IEEE J. Quant. Electron.

Meeting Speeches*

MS No.			
1908B	Modern High Pressure Techniques	J. A. Kafalas	High Pressure Treatment of Materials Meeting, Boston, 7 – 8 November 1968
2015B	Survey of Equipment for High Pressure Studies	M. D. Banus	
2016B	Retained High Pressure Phases and High Pressure Synthesis	M. D. Banus	
1954C	Localized vs Collective Descriptions of Magnetic Electrons	J. B. Goodenough	American Chemical Society, Atlantic City, New Jersey, 8 – 13 September 1968
2327	$SrIrO_3$ – A Study of the High and Low Pressure Forms	J. M. Longo J. A. Kafalas	
2328	The P-T Phase Diagram of InSb at High Temperatures and Pressures	M. D. Banus M. C. Lavine	
1954D	A Phase Diagram for Outer Electrons in Solids	J. B. Goodenough	Colloquium, Johns Hopkins University, 15 October 1968
2112A	High Temperature Techniques for Material Preparation and Crystal Growth	T. B. Reed	Argonne National Laboratory, Argonne, Illinois, 27 September 1968

* Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

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MS No.			
2236A	Raman Scattering from Magneto-plasma Waves in Semiconductors	A. L. McWhorter P. N. Argyres	
2325	Thermal Brillouin Scattering Study of the Attenuation of Hypersound in Quartz	A. S. Pine	
2331	Raman Scattering from Electron Spin-Density Fluctuations in GaAs	D. C. Hamilton A. L. McWhorter	
2332	Light Scattering from Single Particle Electron and Hole Excitations in Semiconductors	A. Mooradian	International Conference on Light Scattering Spectra of Solids, New York University, 3 – 6 September 1968
2333	Raman Scattering from Lattice Vibrations of $GaAs_xP_{1-x}$	N. D. Strahm A. L. McWhorter	
2334	Landau Level Raman Scattering	G. B. Wright P. L. Kelley S. H. Groves	
2335	Light Scattering from Plasmons and Phonons in GaAs	A. Mooradian A. L. McWhorter	
2251A	Homogeneity Ranges and Te_2-Pressure Along the Three-Phase Curves for Bi_2Te_3(c) and a 55-58 at % Te, Peritectic Phase	R. F. Brebrick	
2361	Polymorphism in Selenospinels – A High Pressure Phase of $CdCr_2Se_4$	M. D. Banus M. C. Lavine	American Chemical Society, Boston, 13 – 15 October 1968
2362	The High-Pressure Form of $CsNiF_3$ – A Transparent Ferrimagnet	J. M. Longo J. A. Kafalas	
2363	Thermal Arrests in the Bi-Te System	A. J. Strauss	
2261B	Band Approach to the Transition Metal Oxides	J. Feinleib	Seminar, Sandia Laboratory, Albuquerque, New Mexico, 25 – 27 September 1968
2316	A Phase Diagram for Electrons in Solids	J. B. Goodenough	Seminar, University of Texas, 13 November 1968
2330	Dependence of Critical Properties on Dimensionality of Spins	H. E. Stanley	International Conference on Statistical Mechanics, Kyoto, Japan, 9 – 14 September 1968

MS No.			
2332A, B, C, D	Light Scattering from Elementary Excitations in Solids Using Intense Laser Sources	A. Mooradian	Seminar, Ohio State University, 15 October 1968; Seminar, Purdue University, 19 October 1968; Seminar, Yale University, 22 October, 1968; Seminar, M.I.T. National Magnet Laboratory, 24 September 1968
2340	Tin Doping of Epitaxial Gallium Arsenide	C.M. Wolfe G.E. Stillman W.T. Lindley	International Conference on Gallium Arsenide, Dallas, Texas, 16 – 18 October 1968
2359	Far Infrared Impact Ionization Modulators	I. Melngailis P.E. Tannenwald	NEREM, Boston, 6 – 8 November 1968
2386	Self-Modulation, Self-Steepening and Spectral Development of Light in Small Scale Trapped Filaments	T.K. Gustafson* J-P. Taran* H.A. Haus* J.R. Lifsitz* P.L. Kelley	Gordon Conference, Meriden, New Hampshire, 24 – 30 August 1968
2392	Self-Trapping of a CW Laser Beam in Glasses	R.L. Carman A. Mooradian P.L. Kelley	
2410	Properties of Insulating Regions in GaAs Created by Proton Bombardment	W.T. Lindley A.G. Foyt J.P. Donnelly C.M. Wolfe	Electrochemical Society, Montreal, Canada, 6 – 11 October 1968
2411	Interdiffusion in PbSe	R.W. Brodersen* J.N. Walpole* A.R. Calawa	
2420	Photon-Electron Interactions in Solids	A. Mooradian	Seminar, Purdue University, 18 October 1968
2420A, B, C	Light Scattering from Electrons in Solids	A. Mooradian	Seminar, M.I.T., 11 October 1968; Seminar, M.I.T., 8 November 1968; Seminar, IBM Research Laboratories, Yorktown Heights, New York, 14 November 1968
2429	Maser Emission in Interstellar OH	M.M. Litvak	Seminar, Harvard College Observatory, 23 October 1968
2430	Light Scattering from Electrons in Semiconductors	A.L. McWhorter	Seminar, General Telephone and Electronics Laboratories, Bayside, New York, 28 October 1968

* Author not at Lincoln Laboratory.

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Experiments with the fast far-infrared and submillimeter germanium impact ionization modulator have been extended to p-type Ge samples and additional wavelengths. Much improved depth of modulation has been obtained at all wavelengths investigated and very nearly 100 percent modulation has been achieved for 2-mm wavelength radiation.

In a communications-type experiment, 337-μ cyanide laser radiation was modulated by applying an audio-modulated 300-kHz carrier to the Ge modulator. This radiation was incident on a fast GaAs photoconductive detector which was connected to a radio receiver tuned to 300 kHz, where the audio information was recovered.

Gallium-tin melts have been used in the $AsCl_3$-Ga-H_2 flow system to prepare n-type epitaxial GaAs with accurately controlled, uniform electron carrier densities in the range between 10^{15} and 10^{17} cm^{-3}. The transfer ratio of net tin donor concentration in the epitaxial layer to tin concentration in the gallium melt was examined as a function of seed orientation, seed and melt temperatures and flow rates. Over a wide range of conditions, the tin transfer ratio depends primarily on the growth rate of the epitaxial layer. Doping variations as low as ±2.6 percent have been attained by growing under conditions where system variations have little effect on growth rate.

Infrared transmission, magnetic birefringence and Faraday rotation have been measured in single crystals of EuO in the wavelength range between 1.5 and 20 μ. The most transparent samples have an absorption coefficient at 20°K less than 0.5 cm^{-1} in the range between 2.5 and 9 μ and less than 1.0 cm^{-1} at 10.6 μ. At 20°K and 9 kG, the Faraday rotation varies from 660 deg/cm at 10.6 μ to 3×10^4 deg/cm at 2.5 μ and over 10^5 deg/cm at 1.5 μ. This corresponds to a figure of merit for the specific rotation per unit attenuation of 150 deg/dB at 10.6 μ and $>1.4 \times 10^4$ deg/dB at 2.5 μ.

II. OPTICAL TECHNIQUES AND DEVICES

Frequency response measurements of two Ge:Cu detectors have been obtained by the optical heterodyne technique involving a tunable diode laser.

A stable reference laser has been heterodyned with the CO_2 laser amplifier output and the beat frequency spectra observed with both sealed-off and flowing-gas operation of the amplifier. These measurements showed no significant deterioration of the beat frequency spectrum in sealed-off operation; however, with flowing-gas operation of the amplifier, the envelope of the beat frequency spectrum broadened by about an order of magnitude from 5 to 50 kHz for 1-second observation time.

Stability measurements have indicated that the expected improvements in short-term stability will be achieved in the redesigned version of the stable laser, in addition to the significantly improved ease of assembly, operation, and reduced cost.

Preliminary analysis indicates that it is feasible to measure the spatial correlation of random phase fluctuations of 10-μ radiation propagating in the atmosphere by using a tracking telescope.

Experiments have been carried out to determine the effects of molecular diffusion on the saturation parameter of the CO_2 laser. The equivalent saturation parameter derived from these measurements decreased monotonically from 97 to 35 w/cm^2 as the average input beam radius increased from 0.87 to 2.47 mm in the 9-mm radius discharge tube of the amplifier.

The transmission of the atmosphere for the P(18) and P(22) lines of a CO_2 laser has been measured over a 1.3-km path for partial pressures of H_2O vapor ranging from 10 to 25 mb.

An expression has been derived for the optical heterodyne mixing efficiency as a function of detector position with respect to the focus. The efficiency has been evaluated in a number of important cases.

III. MATERIALS RESEARCH

A numerical scale for the oxygen affinity of metals has been constructed by arranging the metals in order of their "pO" values, where pO is defined as the negative logarithm of the oxygen pressure (in atmospheres) in equilibrium with the metal and its lowest oxide at 1000°K. In general, the oxygen affinity increases as pO increases, since in most cases pO is proportional to the free energy of the reaction in which the metal combines with one mole of oxygen to form the lowest oxide.

The liquidus surface in the Zn-Cd-Te ternary system has been investigated by means of differential thermal analysis. Most of the liquidus temperature measurements were made on samples containing between 50 and 100 atomic percent Te.

A system has been constructed for making differential thermal analysis measurements from 400° down to about 15°K. It has been used successfully to detect the thermal effects accompanying the magnetic transition in CoS_2 at 124°K and the cubic-rhombohedral transformation in $Sn_{0.8}Ge_{0.2}Te$ alloy at 180°K.

Single crystals of $Eu_{3-x}Gd_xFe_5O_{12}$ garnets up to 22 mm on a side have been grown from a $PbO\text{-}PbF_2\text{-}B_2O_3$ flux. Smaller crystals of $Eu_3Fe_5O_{12}$ have been grown from Fe_2O_3 and $BaFe_{12}O_{19}$ fluxes, which are being used in an attempt to reduce contamination of the garnet crystals.

A new series of rare earth compounds, with the type formula $LnCrTeO_6$, has been prepared by reacting mixtures of the metal oxides at 1000°C. These compounds have a structure similar to that of $PbSb_2O_6$, but ordering of Cr and Te to form $Cr^{3+}\text{-}Te^{6+}\text{-}Cr^{3+}$ columns causes a doubling of the c-parameter.

The phase diagram of $CsNiF_3$ has been determined by means of x-ray diffraction measurements on samples annealed at pressures up to 65 kbars and temperatures between 500° and 1000°C. The hexagonal 2-layer structure stable at atmospheric pressure is transformed at less that 5 kbars to a hexagonal 9-layer structure which, in turn, is transformed at about 50 kbars to the hexagonal 6-layer structure reported previously.

Further studies have been made on the structural, electrical, and magnetic properties of the high pressure form of $CdCr_2Se_4$ reported previously. This phase exhibits antiferromagnetic ordering with a Néel temperature of 55°K, whereas the phase stable at atmospheric pressure is ferromagnetic.

IV. PHYSICS OF SOLIDS

The oscillatory magnetoreflection data of bismuth-antimony alloys in the range of composition $0 < \%\,Sb < 15$ have been analyzed in terms of the Lax two-band model. The variation of the band parameters with composition can be understood qualitatively in terms of the change in magnitude of the spin-orbit splitting with alloying.

The Shubnikov-de Haas effect is being used to investigate the Fermi surface of PbTe-SnTe alloys. Measurements have been carried out in 17, 20 and 30% tin alloys in the temperature range 1.25° to 4.2°K with magnetic fields up to 80 kG.

The problem of transport in an impure normal Fermi system has been studied. A quasiparticle transport equation has been derived for this system subject to the limitations of low temperatures, small impurity densities and slowly varying driving fields.

A study has been made of what information can be obtained about the symmetry of the ground state of a system from general considerations. On the basis of a general relation between nodelessness and symmetry of a wavefunction, it is found that the symmetry of the ground level can be predicted for many systems of physical interest.

Recently it was shown that five distinct distant-neighbor B-B exchange interactions can play significant roles in determining the ground state spin configuration in chromium spinels having nonmagnetic A-site ions. Extension of this work to the case of magnetic A-site ions and including A-A interactions has led, in cobalt chromite, to (a) an 8-percent decrease in the theoretical wavelength of the ferrimagnetic spiral, and (b) the prediction of an additional magnetic transition at a temperature of about one-third of T_c. These new results bring the theory into overall agreement with experiment.

A new generalization of Hartree-Fock (HF) theory to nonzero temperature, namely, the Thermal Single-Determinant Approximation, has been applied (a) to a homogeneous interacting electron gas, with the result that a plane wave solution is found with identical thermodynamic behavior to that of the standard thermal HF approximation (STHFA) and (b) to H-atoms, where the new theory gives a lower free energy than the STHFA. Furthermore, the new theory requires that for weakly interacting atoms the one-electron functions ψ_i be localized, whereas the STHFA requires that the ψ_i be extended throughout the crystal.

The fact that the statistical mechanics of the Heisenberg Hamiltonian for infinite-dimensional spin and the exactly soluble spherical model are identical has been used to obtain some useful results. The high temperature expansions are found to agree well with the exact calculations, and a conjectured form of the free energy for the model in a three-dimensional lattice is obtained.

The temperature dependences in α-quartz of the damping of two optic vibrations, the 128 cm^{-1} E-mode and the 466 cm^{-1} A_1-mode, and a longitudinal acoustic vibration along the x-axis have been measured by high resolution Raman and Brillouin scattering. A simple model for the cubic anharmonicity, which includes relaxation broadening of the thermal phonons, accounts satisfactorily for the damping of these modes.

Scattering of light from magnetic excitations in $RbNiF_3$ has been observed below T_c (139°K) and up to ~200°K. The Raman scattering observations give exchange constants which are consistent with magnon-assisted optical absorption and high temperature susceptibility data.

By using an argon-ion laser and a surface reflection technique, Raman scattering from zone center optic phonons has been studied in InSb and InAs from 5° to 300°K. In both these

semiconductors an enhancement of the LO phonon scattering intensity takes place when the laser frequency is near an interband transition. LO phonon scattering enhancement and also a decrease in the LO scattering frequency are obtained when an InAs surface is biased with an electric field. The latter InAs results are explained in terms of the change in dielectric constant with surface electric field.

The effect of spin-density fluctuations on the scattering from single particle excitations in GaAs has been studied. Because charge-density fluctuations are screened out in high electron concentration materials, while spin-density fluctuations are not, the spin-density fluctuations play an important role in this case. The polarization properties of the two mechanisms are also found to be different.

Careful evaluation of two single electron mechanisms proposed to explain the magneto-Raman process with $\Delta n = 1$, $\Delta s = 0$ in InSb (namely, interactions (a) due to the linear k, inversion asymmetry terms in the E(k) of the valence band and (b) between Landau levels which occur with $k_3 \neq 0$, where k_3 is along the magnetic field) gives a cross section several orders of magnitude smaller than experimental results. This suggests that other mechanisms, such as Coulomb interactions, are important. Objections are raised to previous theoretical estimates of this cross section.

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This Quarterly Technical Summary covers the period from 1 August through 31 October 1968. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

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